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Comparison of Yields of Several Cultivars of Field-Grown Soybeans Exposed to Simulated Acidic Rainfalls

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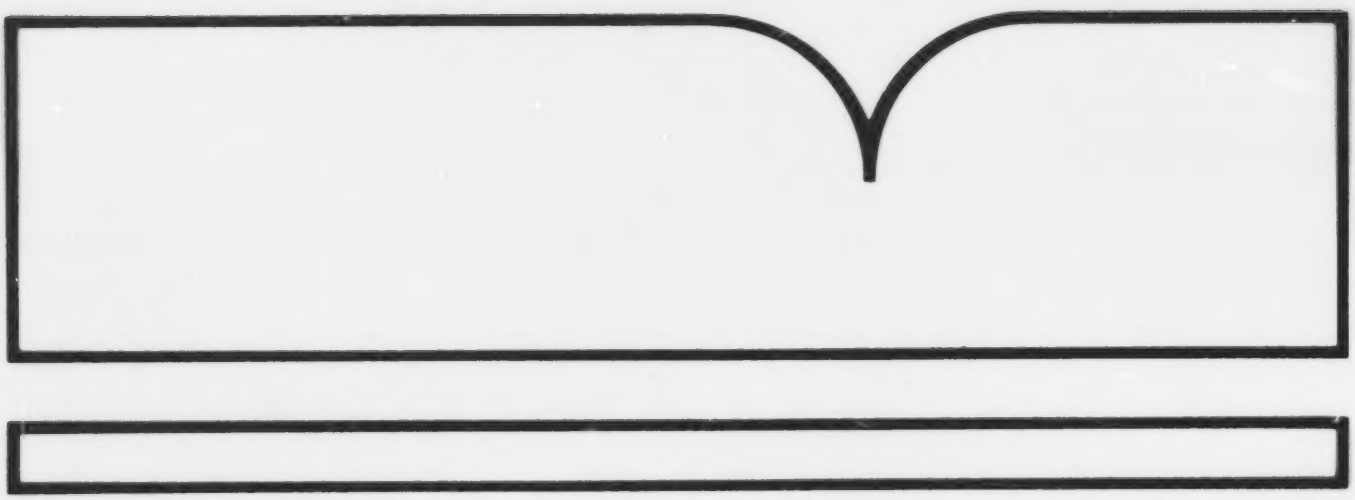

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16. ABSTRACT

Rainfall acidity response functions for crop yield and growth are necessary to predict the overall impacts on crop yields of ambient and/or anticipated levels of acidic rain. The experiment described herein was performed at Brookhaven National Laboratory to determine the effects of simulated rainfalls of pH 5.6, 4.4, 4.1 and 3.3 on seed yields of four cultivars of field grown soybeans. Soybeans were chosen because previous results suggested that certain varieties of this crop are sensitive to rainfall acidity and because they are an economically important crop in the United States. Sixteen plots per treatment were used. Plants were grown using standard agronomic practices under automatically moveable rainfall exclusion shelters which minimized changes in the plants' microclimate. Soybeans of cv. Amsoy shielded from ambient rainfalls and exposed to simulated rainfalls of pH 4.4, 4.1 and 3.3 exhibited yields that were 11.5, 10.4 and 11.7% respectively, below those of plants exposed to rain of pH 5.6. The comparable figures for other cultivars were as follows: Asgrow 3127 - 14.5, 12.2 and 9.0%; Corsoy - 13.7, 12.7, and 7.8%; Hobbit - 9.2, 6.2 and 16.6%. Most of the observed decreases in seed mass per plant and per unit area for these four cultivars appear to have resulted from a corresponding decrease in pod number per plant.

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COMPARISON OF YIELDS OF SEVERAL CULTIVARS OF FIELD-GROWN SOYBEANS EXPOSED TO SIMULATED ACIDIC RAINFALLS

BY LANCE S. EVANS[1,2], KEITH F. LEWIN[1], ELIZABETH M. OWEN[2] AND KAREN A. SANTUCCI[2]

[1] *Terrestrial and Aquatic Ecology Division, Department of Applied Science, Brookhaven National Laboratory, Upton, NY 11973 and* [2] *Laboratory of Plant Morphogenesis, Manhattan College, The Bronx, New York 10471, USA*

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SUMMARY

Rainfall acidity response functions for crop yield and growth are necessary to predict the overall impacts on crop yields of ambient and/or anticipated levels of acidic rain. The experiment described herein was performed at Brookhaven National Laboratory to determine the effects of simulated rainfalls of pH 5·6, 4·4, 4·1 and 3·3 on seed yields of four cultivars of field grown soybeans. (*Glycine max* Merrill). Soybeans were chosen because previous results suggested that certain varieties of this crop are sensitive to rainfall acidity and because they are an economically important crop in the United States. Sixteen plots per treatment were used. Plants were grown using standard agronomic practices under automatically moveable rainfall exclusion shelters which minimized changes in the plants' microclimate. Soybeans of cv. Amsoy shielded from ambient rainfalls and exposed to simulated rainfalls of pH 4·4, 4·1 and 3·3 exhibited yields that were 11·5, 10·4 and 11·7 %, respectively, below those of plants exposed to rain of pH 5·6. The comparable figures for other cultivars were as follows: Asgrow 3127 – 14·5, 12·2 and 9·0 %; Corsoy – 13·7, 12·7 and 7·8 %; Hobbit – 9·2, 6·2 and 16·6 %. Most of the observed decreases in seed mass per plant and per unit area for these four cultivars appear to have resulted from a corresponding decrease in pod number per plant.

Key words: Acidic rain, seed yields, soybeans, dose–response functions, *glycine max*.

INTRODUCTION

Response functions describing rainfall acidity versus crop yield are needed in order to predict the overall impacts of ambient or anticipated levels of acidic rain on crops. Over the past decade, many experiments, with a variety of techniques, have been performed with field-grown soybeans to determine the effects of changes in acidity of simulated rainfall on seed yields (Evans *et al.*, 1981, 1983; Irving & Miller, 1981; Heagle *et al.*, 1983; Troiano *et al.*, 1983; Banwart, Hassett & Vasalis, 1984; Evans, Lewin & Patti, 1984). From available evidence, it appears that the Amsoy cultivar of soybeans is negatively affected by high rainfall acidity, while the Williams cultivar does not appear to be affected (Evans *et al.*, 1984; Banwart *et al.*, 1984). The experiment described herein was performed with four commercial cultivars to determine their sensitivities to simulated rainfall acidity, all ambient rainfalls being excluded by automatically operated rainfall exclusion shelters (Lewin & Evans, 1984).

MATERIALS AND METHODS

The soil at the research site is a Plymouth Loamy Sand with a silty substratum (Warner *et al.*, 1975). Prior to planting, a rye cover crop was rototilled to a depth

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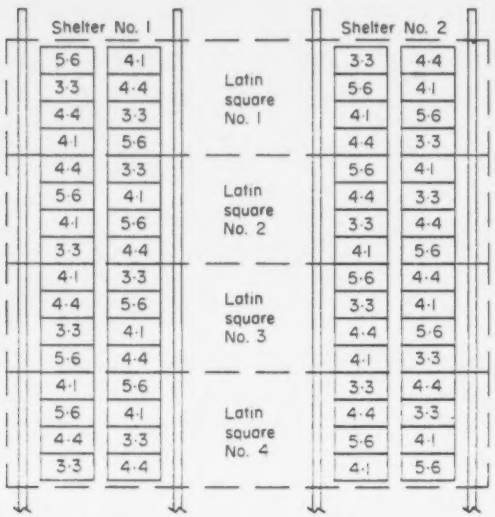

Fig. 1. Field plot layout of the four latin squares within the two rainfall exclusion shelters.

of 23 cm. Plots were fertilized (179 kg ha^{-1}, 10:10:10:5, N:P:K:S), following recommendations based on soil tests performed by Cornell University. Seeds of soybean (*Glycine max*) (cultivars Amsoy 71, Asgrow 3127, Corsoy 79, and Hobbit) were inoculated with *Rhizobium japonicum* and planted in 38·1 cm wide rows on 11 June 1984. Under the exclusion shelters the initial plant stand of approximately 480000 plants per hectare was thinned to provide a population of about 440000 plants per hectare. Ambient exposure plots were not thinned. Each experimental plot consisted of eight adjacent rows, 1·52 m in length. Immediately after planting, the fields were sprayed with a tank mix of Lasso (Alachor; Monsanto, St. Louis, MO) and Sencor (Metribuzin; Mobey Chemical Corp., Kansas City, MO) at rates of 2·24 and 0·28 kg ha^{-1} of active ingredient, respectively.

Four replicates of four experimental treatments consisting of four simulated acidic rainfalls (pH 5·6, 4·4, 4·1 and 3·3) were arranged into each of four latin squares yielding a total of 16 replicate plots per experimental treatment (Fig. 1). The latin squares used were selected randomly from those given in table XV of Fisher & Yates (1957). Each plot consisted of eight rows from east to west; two rows each of Corsoy, Amsoy, Asgrow, and Hobbit, respectively (Fig. 2). Hobbit is a determinant cultivar, while the other three cultivars are indeterminant. All eight rows received simulated rainfalls. Each plot was 1·52 m long by 3·05 m wide and was treated with two nozzles, each covering a 1·5 by 1·5 m area. Since the centre two rows of each plot were on the edge of the spray patterns of these two nozzles they were not sampled. Similarly, the outer row on each side of the plot and the ends of the rows in each plot were not harvested. Fifteen plants of each cultivar were harvested from each plot. The length of row occupied by these 15 plants of each cultivar harvested was recorded so that yields could be expressed on both per area and per plant bases. Harvested plants were dried to a constant weight at 60 °C. All pods that had at least one enlarged seed were removed from the plants and counted. Seeds from these pods were removed, counted, and weighed.

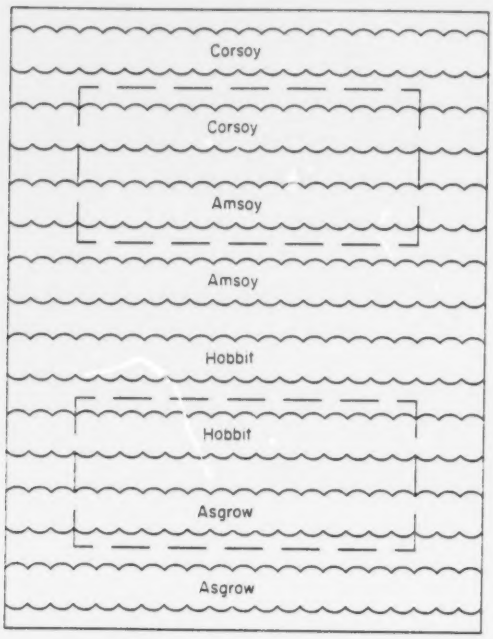

Fig. 2. Layout of the positions of the four cultivars within each plot. The Corsoy cultivar was always on the eastern side and the Asgrow was on the western side of each plot. Plants of each cultivar taken for harvest were from the areas within dashed rectangles.

Table 1. *Experimental design*

Duration of the experiment	16 weeks (11 June–1 October 1984)
Duration of experimental treatments	15 weeks (12 June–21 September 1984)
Number of plots per treatment	16
Individual plot area	4·6 m^2
Number of harvested plants per cultivar per plot	15
Frequency of rainfalls	2 per week
Total number of rainfalls	30
Duration of each rainfall	80–90 min
Total water deposition for all simulated rainfalls	311 mm

	Simulated rain solution chemistry			
Treatment acidity (pH)	Sulphate concentration ($mg\ l^{-1}$)	Nitrate concentration ($mg\ l^{-1}$)	S deposition ($kg\ ha^{-1}$)	N deposition ($kg\ ha^{-1}$)
5·6	1·3	0·67	4·0	2·1
4·4	2·6	1·3	8·1	4·0
4·1	3·9	2·0	12·1	6·2
3·3	18·0	9·5	56·0	30·0

Simulated rain solutions

The concentrations (mg l^{-1}) of chemicals in the simulated rain before additions of acid were NaCl: 2·12; $(NH_4)_2$ SO_4: 1·27; $NaNO_3$: 0·884; $MgSO_4.7H_2O$: 0·789; $CaCl_2$: 0·321; NH_4Cl: 0·284; and KCl: 0·277. Concentrations and total depositions of S and N within the simulated rain solutions are shown in Table 1. A 2·5 :1·0 equivalent ratio of sulphate to nitrate was used for all the simulated rainfall treatments, which began on 12 June and ended on 21 September 1984 when almost all leaves were senescent. Harvest began on 1 October 1984 after senescence was complete. The 20·7 mm of water provided each week as simulated rain is equal to the weekly average of ambient rainfalls at the research site during the growing season (Nagle, 1975).

Insect infestations

Infestations of Mexican bean beetles (*Epilachna varivestis*), Japanese beetles (*Popilla japonica*), green cloveworm (*Plathypena scabra*) and two-spotted spider mites (*Tetranychus urticae*) were controlled using appropriate insecticides (Sandsted *et al.*, 1984) applied at label recommended rates.

Rainfall shielded plots

Soybean plants were shielded from all ambient rainfalls by the use of automatically moveable shelters (Lewin & Evans, 1984) of standard plastic greenhouse construction, which were moved automatically on rails over the entire crop within 60 s after a raindrop shorted across a grid on an electronic rain sensor. Simulated rainfalls were applied between 1800 and 2400 h. No supplemental irrigation was provided to the shielded plots.

Ambient rainfall plots

Soybeans were also planted adjacent to the shielded plots. These plants were not, and should not be considered to represent statistical controls for the shielded plots. Their purpose was to provide estimates of seed yield for these four varieties when grown under standard agronomic practices without any experimental or artificial treatments such as additions of simulated rain, exclusion of ambient rainfall, or hand-thinning to achieve a desired plant population. Although in some years supplemental irrigation is needed at this research site to obtain high soybean yields, none was needed during this experiment.

Statistical analyses

Statistical analyses were performed on all data to determine if treatments within each variety were significantly different at $P < 0·05$. An analysis of variance followed by the Student–Newman–Keuls Test was performed to determine statistical significance (Steel & Torrie, 1960). A weighted least squares regression analysis was performed with all the means of the 16 plots per treatment. The best fit treatment (pH)-response (per plant yield) function and the correlation coefficients of regression analyses are given when significant.

RESULTS

An analysis of variance of the data from this experiment indicates that the variation among pH levels is significantly different but the cultivars respond to the

Table 2. *Analysis of variance of the field experiment with all four soybean cultivars*

Source of variation	D.F.	S.S.	M.S.	*F*
Among Latin Squares	3	12·78	4.26	—
Among pH levels	3	33·69	11·23	10.03**[b]
Linear	1	—	17·12	15·29**
Quadratic	1	—	11·85	10·58**
Cubic	1	—	4·72	4·21
Among cultivars	3	382·14[a]	—	—
Cultivars × pH	9	6·75	0·75	0·95[c]
pH × LS	9	10·10	1·12	—
Cultivars × LS	9	23·93[a]	—	—
pH × cultivars × LS	27	21·44	0·79	1·27[d]
Among rows wi LS	12	115·51	9·63	—
Among columns wi LS	12	33·76	2·81	—
Cultivar x rows. wi LS	36	82·77[a]	—	—
Cultivar × cols wi LS	36	22·02	0·61	—
Residual wi squares	96	59·91	0·62	—
Total	255	804·80	—	—

[a] These lines in the ANOVA may be partitioned only for purposes of calculating their sum due to a systematic arrangement of cultivars within plots.

[b] pH levels tested with (pH × LS) M.S.

[c] Cultivars × pH levels tested with (pH × cultivars × LS) M.S.

[d] (pH × cultivars × LS) interaction tested with residual.

**$P < 0{\cdot}01$.

The ANOVA used for this analysis was taken from the example on page 296 of Federer (1955).

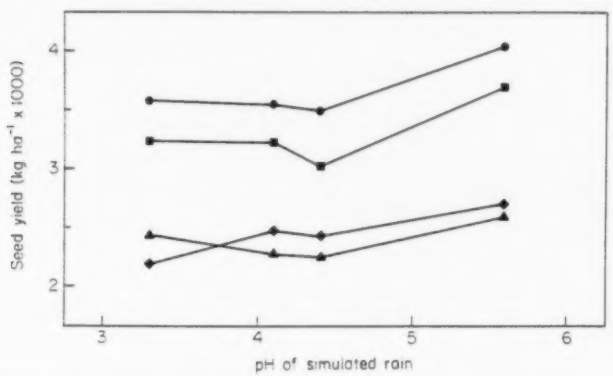

Fig. 3. Seed yield responses of four cultivars of field-grown soybeans exposed to simulated rain of various acidity levels. ●, Amsoy; ■, Asgrow; ◆, Hobbit; ▲, Corsoy.

treatments in a similar manner (Table 2). As a result, no separate analysis of variance was performed for each cultivar.

The overall responses of the four cultivars to simulated rainfall acidity are shown in Figure 3. Amsoy plants shielded from ambient rainfalls and exposed to simulated rainfalls of pH 4·4, 4·1 and 3·3 exhibited yields 11·5, 10·4 and 11·7% respectively, below yields of plants exposed to simulated rainfalls on pH 5·6 (Table 3). For the other cultivars, the comparable figures were: Asgrow – 14·5, 12·2 and 9·0%; Corsoy – 13·7, 12·7 and 7·8%; Hobbit – 9·2, 6·2 and 16·6%.

Table 3. *Seed yield characteristics of four cultivars of field-grown soybeans exposed to simulated acidic rain*

Cultivar	Treatment	Seed mass per plant (g)	Pod number per plant	Seed number per plant	Seed number per pod	Mass per seed (g)	Seed yield (kg ha^{-1})	Plant population (number ha^{-1})
Amsoy	5·6	9·11^{a}	19^{a}	48^{a}	2·6	0·19	4030^{a}	446000
	4·4	8·06^{b}	16^{b}	42^{b}	2·6	0·19	3490^{b}	437000
	4·1	8·16^{b}	17^{b}	43^{b}	2·6	0·19	3540^{b}	434000
	3·3	8·04^{b}	16^{b}	42^{b}	2·6	0·19	3570^{b}	445000
	Ambient	7·90	16	42	2·6	0·19	3650	467000
Asgrow 3127	5·6	8·00^{a}	22^{a}	56^{a}	2·5^{a}	0·14	3690^{a}	461000
	4·4	6·84^{b}	20^{a,b}	50^{a,b}	2·5^{a}	0·14	3020^{b}	441000
	4·1	7·02^{b}	20^{b}	47^{b}	2·4^{b}	0·15	3220^{b}	459000
	3·3	7·28^{b}	20^{b}	51^{b}	2·5^{a}	0·14	3230^{b}	443000
	Ambient	7·55	20	50	2·4	0·15	3720	496000
Corsoy	5·6	6·14^{a}	22	45^{a}	2·1	0·13	2590^{a}	422000
	4·4	5·30^{b}	20	39^{b}	2·0	0·13	2240^{b}	423000
	4·1	5·36^{b}	19	41^{a,b}	2·1	0·13	2270^{b}	424000
	3·3	5·66^{a,b}	20	42^{a,b}	2·1	0·14	2430^{a,b}	429000
	Ambient	4·67	18	38	2·1	0·12	2160	469000
Hobbit	5·6	5·84^{a}	20^{a}	42^{a}	2·1	0·15	2700^{a}	463000
	4·4	5·30^{b,c}	18^{b}	37^{a,b}	2·1	0·14	2420^{b}	455000
	4·1	5·48^{a,b}	17^{b}	36^{b}	2·1	0·16	2470^{b}	450000
	3·3	4·87^{c}	16^{b}	34	2·1	0·14	2180^{c}	451000
	Ambient	6·96	22	46	2·1	0·15	3090	445000

Mean values followed by a different letter within each parameter are significantly ($P < 0·05$) different by analysis of variance (Steel & Torrie, 1960). Values followed by the same letters or no letters are not significantly different. Analysis of variance comparisons are made only among treatments within each cultivar.

With all four cultivars, most of the observed changes in seed mass per plant and seed mass per hectare appear to have resulted from corresponding changes in the number of pods on the plants at harvest. The Asgrow cultivar did show a significant difference between treatment means for seed number per pod, but the magnitude and locations of this difference can account for only minor portions of the observed effects of acidity on yield.

Qualitative observations on the condition of plants were also recorded. Foliar injury was observed only on young plants shielded from ambient rainfalls and exposed to simulated rainfalls of pH 3·3. Plants exposed to simulated rainfalls of pH 4·1, 4·4 and 5·6 exhibited no visible foliar injury attributable to rainfall acidity.

Discussion

The experimental results show that seed yields of soybeans are reduced by acidic simulated rainfall treatments. These reductions in seed yield resulted mainly from a decrease in the number of pods on each plant at harvest and are reflected in both the number of seeds per plant and the mass of seeds per plant. A decrease in the number of pods harvested per plant may result from either a decrease in flower pollination and fertilization, a decrease in pod retention, or the inadequate development of young pods. Preliminary observations indicate that the decrease in number of pods per plant with high rainfall acidity may result from a loss or lack of filling of enlarged pods during the last month of the growing season.

Bean yields for Amsoy plants shielded from ambient rainfalls and exposed to twice weekly simulated rainfalls of pH 5·6 were consistent among the growing seasons of 1981 (4600 kg ha^{-1}); 1982 (4590 kg ha^{-1}); 1983 (4260 kg ha^{-1}); and 1984 (4030 kg ha^{-1}). These relatively consistent yields under rainfall exclusion conditions with uniform rainfall acidity and amount can be contrasted with the more variable yields of plants exposed to ambient rainfalls which vary in frequency, duration, and volume from year to year. Yields of Amsoy plants exposed to ambient rainfalls for 1981, 1982, 1983 and 1984 were 4460, 4000, 4820 and 3650 kg ha^{-1}, respectively. Differences in yields of plants grown in successive years under ambient conditions may be attributed, in part, to annual weather variations and differences in planting dates and plant populations. During three of the four growing seasons mentioned above, ambient rainfalls varied markedly, totalling 212, 457, 361 and 411 mm in 1981, 1982, 1983 and 1984, respectively. Moreover, planting dates and germination rates can vary from year to year depending upon the weather during the planting season. Due to its ability to control moisture availability, the exclusion shelter system provides relatively consistent bean yields from year to year in spite of markedly different climatic conditions. In this manner, crop yields and overall responses can more readily be compared among years to determine the overall effects of acidity.

During the 1984 growing season, all four soybean cultivars tested had similar responses to acidic deposition. Specifically, yields of all cultivars exposed to all acidic deposition levels (pH 4·4, 4·1 and 3·3) were below yields of plants exposed to pH 5·6. The significant main effect of pH in the combined analysis may be considered as a difference between 5·6 and the 4·4, 4·1 and 3·3 acidic pH levels. A graph of the cultivar means (Fig. 3) shows that while a linear effect is adequate to describe the response of Amsoy and Hobbit, Corsoy shows a quadratic effect and Asgrow simply a difference between 5·6 and the more acidic pH treatments. The simplest explanation for the observed result that 'higher doses of acidic rain

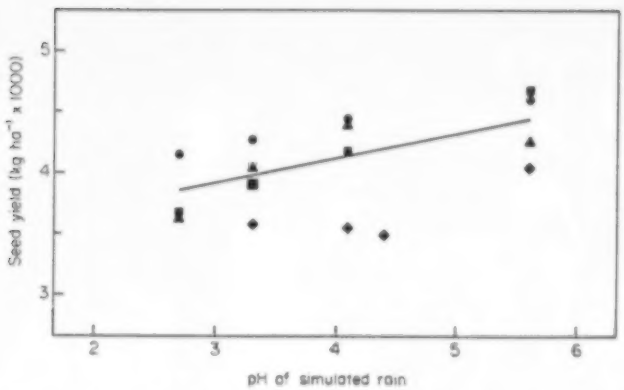

Fig. 4. Comparison of seed yield results from four rainfall exclusion experiments at Upton, New York in which field-grown soybeans were exposed to simulated acidic rain. The line drawn is from least squares analyses weighted for the number replications per treatment per year. The line is represented by $y = 3310 + 220\ x$ (y is seed yield in Kg ha^{-1}, and x is the pH of the simulated rain). The linear regression of the data is significant ($P = 0{\cdot}0165$). The quadratic regression is not significant. ■, 1981; ●, 1982; ▲, 1983; ◆, 1984.

do not cause further reduction in yield' is that the variation inherent in the soybean response in the experimental designs used does not permit a critical discussion of specific polynomial functions for individual cultivars over a range of four pH levels for a single year of experimentation. Thus, a linear response has been frequently cited to account for treatment differences as a model of least resistance. Moreover, the decrease in yields of all cultivars was mainly due to a decrease in the number of pods per plant. This relatively consistent response to acidity among cultivars is particularly significant when it is considered that there are marked varietal differences in seed mass per plant, seed number per plant, seed number per pod, total yield, etc. (Table 2).

The experimental results obtained at Brookhaven National Laboratory over several growing seasons (1981, 1982, 1983 and 1984) indicate that acidic rainfalls which occur during the growing season may decrease the seed yield of the Amsoy 71 soybean cultivar under field conditions (Figure 4). The single combined function which is visually represented as a line is given to show the general positive association between increasing pH and seed mass in spite of variability of responses from year to year. The line reflects a weighted analysis based on the number of plots per mean, since the experiments differed in replication, pH level selection and environmental conditions over the years. It also appears, based on two years of experiments (1982 and 1983), that the Williams 79 cultivar is insensitive to rainfall acidity when exposed to conditions equal to those that consistently caused yield reductions of Amsoy (Evans *et al.*, 1984, 1985). The results of the experiment in 1984 indicate that Asgrow, Corsoy, and Hobbit may also be sensitive to acidic deposition. Documentation of the effects that precipitation acidity has on other cultivars is needed for any overall assessment of acidic rain on soybean production. These results substantiate previous results that show that some soybean cultivars are adversely affected by simulated acidic rainfalls within the range of natural precipitation acidity. At the present time, it appears that acidic deposition can

adversely influence certain soybean cultivars, but the mechanism of this influence and the degree to which other environmental and edaphic factors can affect this response remain obscure.

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